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Research article

Zero discharge: Pilot project for biodegradation of cattle effluent by pyroclastic “lapilli” treatment for fodder irrigation

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ABSTRACT

Livestock effluents are a nutrient supply that is beneficial for crops, so their use is essential to guarantee the sustainability of the global management of farms. Zero discharge cattle effluent management to irrigate fodder crops is a mitigation option, so it is considered a key factor for adaptation to climate change. This paper presents the result of an “on site” pilot scale (three-stage, vertical flow filtration system using lapilli). This is a low-cost solution in terms of finance and energy, which does not require the addition of chemicals, to treat a cattle effluent. The effluent's quality obtained allowed it to be injected in a drip system with low risks of obstruction. And the pilot system allowed to obtain elimination values for the main parameters of effluent's quality (TSS and COD, 98% and 80% respectively) similar or greater than the ones obtained in other treatments of low cost and energy, and gives values contemplated in reclaimed water reuse guidelines of many countries. Furthermore, elimination rate for the BOD_5 obtained 35 mgL^{-1} in treated effluent. High removal rates were obtained for N, P, K, Cu, Fe and Mn, medium for Ca, Mg and Zn and low for B and Na. These shows that the pilot system and fodder crop combination provide an optimal solution to small farms, controlling sanitary risks. The tested flow allows the use of this system by conventional small farms, which represented 94% of total cow farms in Canary Islands.

1. Introduction

Ecological wastewater treatment systems (EWTS), which are well adapted to rural communities, are also feasible options for livestock effluent treatment. They are designed to take advantage of many of the same processes that occur in nature, but do so within a more controlled environment (Vymazal, 2010). They are low-tech and energy-efficient on site treatments, mechanically simple and with relatively low operation and maintenance (O&M) requirements.

Wastewater treatment and its use in agriculture were evaluated by Pescod (1992) and Westcot (1997) many years ago. However, adoption of water reuse solutions remains limited, among other reasons, because of a lack of common EU environmental/health standards for reclaimed wastewater (EU, 2016 and AMEC FW et al., 2016). The replacement of other water resources for irrigation is highly dependent on whether the health risk and environmental impacts entailed (Pedersen et al., 2005) are allowable or not (Angelakis et al., 1999).

Constructed wetlands (CWs) and other natural systems frequently used for wastewater treatment are based on subsurface horizontal (HF) and vertical (VF) flow, and stabilization ponds (SP) or their combinations. Oxygen-rich conditions inside the bed matrix of VF wetlands support aerobic organic decay and nitrification (Brix and Arias, 2005). Although some authors point out that HF CWs provide high removal of organics and suspended solids but low removal of nutrients (Vymazal, 2005), this property makes them optimal if effluent is going to irrigate fodder crops. Therefore, if the effluent is going to be used in a drip irrigation system (DI), the treatment should essentially reduce suspension solids (SS), COD, BOD5, and only if needed, salinity and nutrients must be removed (depending on the water dosage, plant tolerance and nutrient demands). In this sense, if the designed treatment controls sanitary risks and avoids clogging problems in the irrigation system, then, conserving nutrients for reuse will increase sustainability of livestock farming, even more in subtropical countries where water and fertilizer resources are scarce or expensive. Also, low concentrations of heavy metals or other toxic pollutants in reuse effluent are very desirable (Marecos Do Monte and Albuquerque, 2010). The heavy metal

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presence is highly influenced by effluent origin (not frequent in livestock manure). EWTS present a wide variation in removal efficiency among systems as well as among pharmaceuticals (Vymazal et al., 2017). Thus, the use of agricultural soils as an advanced treatment to reduce toxic pollutants is a good alternative. In eco-efficient agriculture soil microorganisms remove organic contaminants in a very efficient way (Pagano et al., 2017). Microorganisms growth is enhanced by the provision of organic carbon's.

CWs and waste SP are the most widely used ecological wastewater treatment systems in the world (Zurita et al., 2012). CWs are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters (Vymazal, 2010). Under this point of view, disadvantages of CWs are high needs of land surface and O&M to remove vegetation, and the mineral losses by plant uptake. CWs can be built with or without free water surface. Free water surface can add sanitary risks in warm regions in which enteric bacteria are able to survive in pond water for periods longer than one month (Tejedor et al., 1998; Palacios et al., 2001; Tejedor-Junco et al., 2005). As a one-stage system is usually not sufficient to affect pathogen reduction to safe target levels (Abreu-Acosta and Vera, 2011; García et al., 2013), most authors design two or more phases combining different systems. In a comparative study of three different two-stage hybrid EWTS (Zurita and White, 2014), the authors concluded that the most effective systems were those systems containing a vertical flow component.

In relation to health hazards, WHO-FAO guidelines (Winpenny et al., 2013) recommend defining realistic health-based targets and assessing and managing risks along the continuum – from wastewater generation to consumption of what its produced by cultivating with wastewater – to achieve these targets. This allows a regulatory system in line with the socio-economic realities of the country or locality. The document analyses different options in recycled water used for irrigation. According to the authors, subsurface drip irrigation, SDI, demands lower level of treatment than any other alternative, improving health security by preventing of the contact between water and stems and leaves and, thus, minimizing sanitary risk. SDI has other advantages: water-conserving production practices and mechanization of high yielding crops (Camp, 1998) and uses the soil as an advanced treatment medium. Furthermore, considering that the farming land operations are compatible with the installation of the SDI when reusing reclaimed water, this irrigation system can be proposed as the best one to reuse natural treated livestock effluent (Palacios et al., 2008).

Among alternatives to liquid livestock waste management, filtration consists on the retention of suspended solids and pathogens, leaving nutrients in the filtrate. EWTS must use abundant, low-cost and local materials as filtration media. In volcanic areas, lapilli meets these requirements. Lapilli is a pyroclastic material with diameter between 2 and 64 mm. In comparison with sand materials, it has significant microporosity and often contains amorphous weathering products such as hydrated iron oxides and allophane. These reactive materials have the potential to remove phosphorus (P) and other anionic and cationic species from farm drainage wastewater (Ballantine and Tanner, 2010). In a comparative study of filter materials for P removal conducted by these authors, the score obtained by lapilli was maximum. In the Canary Islands, pyroclasts are frequently used as agricultural soils, either by direct ploughing or as mulchs, therefore plenty of information is available on their behaviour: weathering, solute release, and mechanical properties (Hernández-Moreno et al., 2007; Sustradep, 2008).

Sustainable management of natural resources is a key factor for adaptation to climate change and to ensure food security in smallholder agriculture. Manure management and application represents more than 10% from the total agricultural emissions in CO_2 equivalent (Winpenny et al., 2013; FAO, 2016). As pointed out by Bispo et al. (2017) both, emitting greenhouse gases, (GHG) fluxes and C stocks in soil, are complex to measure, as they are governed by climate and soil characteristics. In addition, the use of fertilizers and residues play an important role. As financial mechanisms where a payment will be made for reducing emissions or increasing C stocks in soils (mitigation options based on soil management) are now to be implemented (Thamo and Pannell, 2015), and soil organic matter plays a crucial role in maintaining soil fertility (Lal et al., 2007), effluent management in rural communities must include the CO_2 fluxes calculation. Therefore, C sequestration in soils can be considered as a “winwin” strategy since it can reduce vulnerability to erosion and improve soil biodiversity and fertility (UNCCD, 2015; UNFCCC, 2016). Zero discharge cattle effluent management to irrigate fodder crops can be considered as mitigation for adaptation to climate change, and to ensure food security in smallholder agriculture. It can be included on soil management strategies and thus, can receive a payment for reducing emissions or increasing C stocks in soils.

In Canary Islands there are 435,000 ruminants, from which bovine represents 4% (ISTAC, 2012). It is estimated that each day, effluent and water used for cleaning generate 60L of residue per bovine. To dispose effluent as a fertilizer (1 ha/3.5 of cattle) (RD 515/2009), 5250 ha would be necessary for bovine effluent disposal. Thus, the system proposed represents an alternative to semi-intensive farms. Previous studies concluded that cropping fodder on restored agricultural lands to feed cattle might be assigned the highest priority among the 10 environmental indicators (Banos-Gonzalez et al., 2016).

The main purpose of this project is to present the results of an “on site” pilot scale (three-stage, subsurface, vertical flow constructed wetland), of a low-cost solution in terms of finance and energy, which does not require the addition of chemicals, to treat a cattle effluent. The final effluent can be later used in subsurface drip irrigation systems (in which the soil acts as subsequent advanced treatment) to produce forage (zero discharge cattle effluent solution).

2. Materials and methods

2.1. Laboratory preliminary experiment

In a preliminary study carried out in lab conditions, Falcón-Cardona et al. (2015) characterized lapilli-filled columns under hydraulic and chemical criteria, using the same material and flux used in this experiment.

2.2. Experimental setup and effluent flow

A pilot scale treatment was performed using six cylindrical drums of 1.2 m height and 0.5 m in diameter: the first one acting as a storage tank (ST), Drums filled with lapilli at a height of 0.7 m: D1, D2 and D3 (at 2.5 m, 1.9 and 1.3 m high above ground, respectively), a 5th drum which receives the filtrated effluent (ST2) and the last one, ST3, situated ona shed (both on the ground). One submersible electric pump (0.75 CV) for draining sewage elevates the flow from ST to D1, in which the flow (as many of VF treatment wetlands), typically goes through cycles of saturation and unsaturation. From drums D1 to D2 and subsequently to D3, the effluent goes down under gravity force. Once regulated its faucets aperture, both D2 and D3 are always in unsaturated conditions. ST2 stores the filtered effluent outside a shed and is connected with the sixth drum (ST3), in which a second submersible electric pump (0.5 CV) propels the filtered effluent to the drip irrigation system, (map and photography in supplementary material).

In the first phase, a flow of 108.5 $mLmin^{-1}$, (equivalent to 9.21 $Ls^{-1}m^{-2}$, the same as used in lab experiment), was established by regulating the faucets aperture between D1-D2 and D2-D3, remaining always in unsaturated conditions. Two experiments with adsorbable (P: inorganic phosphorus) and nonadsorbable (Br: bromide) tracers were conducted. Br took 30 min to reach the outflow of D3. Regarding adsorption, the overall P retention value of the system reached 62% and no bromide retention was obtained. More details on the experimental

setup and drums calibration process can be consulted in Artal et al. (2016). Once the system was calibrated, the effluent was poured at the same flow used in the column experiment. In the second phase, a higher flow of 1140 mLmin^{-1} was used.

2.3. Characterization of slurry

The same livestock effluent used in lab experiment was intermittently dosed to the head of the system. The effluent parameters analyzed were: pH, Electrical Conductivity, EC (electrometric standard methods), chemical oxygen demand (COD, by using a test kit (reference 0–29, 1500, Nanocolor CSB)), biochemical oxygen demand after 5 days (BOD_5, by measuring oxygen by selective electrode), total suspended solids (SStot), volatile suspended solids and total solids (SSvol and TS respectively, measured only once, APHA, 1992), total N (NT, One test kit: reference 985, 088, Nanocolor), nitrate (Ion Chromatography), ammonium (indophenol method), total phosphorus, boron and major metal constituents (Na, K, Ca, Mg, Cu, Mn and Zn) were analyzed by optical emission spectrometry, ICP_OES.

The determination of these parameters in the different conducted experiments is performed on four samples, the ruminant effluent (E), the output from D1 and entry of D2 (output D1), the output from D2 and entry D3 (output D2) and the final output from the system (output D3).

Filter performance was assessed through the removal efficiency for a given parameter p (R_p), achieved in each drum, which was calculated as:

$$R_p = ((E_p - D_{pn})/E_p)*100 \quad (1)$$

where E_p is the value of each parameter of the effluent (at the D1 inlet) and D_{pn} is the value of each parameter at the respective drum outlet.

3. Results and discussion

During the sampling period, effluent quality in terms of COD and SStot presents a high variability among samples: from 3200 to 525 mgL^{-1} and from 2990 to 530 mgL^{-1}, respectively. This result is compatible with the differences due to farm management practices (temporal variability among ages and animal numbers, amount of water used for cleaning…) through time. However, lower variability of BOD_5 is measured among samples, ranging from 340–330 mgL^{-1}. Consequently, BOD_5/COD ratios varied along the experiment from 65% to 10%.

The proposed filtration system efficiently removed COD (mgL^{-1}) both using a flow of 108.5 mLmin^{-1} (Fig. 1: left) and when using a faster one (1140 mLmin^{-1}, Fig. 1: right), reaching similar final COD values. In these experiments the removal rate of COD was lower when using the slower flow. This controversial result is due to the lower SS of the ruminant effluent used in the slower flux experiment (Fig. 2b versus Fig. 2d), as SS are efficiently removed in the range of the studied fluxes and the removing range is function of initial values. The lower removal rate of COD in comparison with SS can be explained considering that an important fraction of COD is soluble, then less retained.

The filtration system presents good results regarding BOD_5 elimination, as removing rates of around 70, 80 and 90% were obtained for D1, D2 and D3, with final values of 35 mgL^{-1}. Effluents reaching these values can be safely injected in drip irrigation systems, avoiding clogging hazards (Nakayama et al., 2007). Although this parameter is not present in Spanish Law for water reuse, guidelines used in other European countries as in "Cyprus Code of Practice" (Anayiotou, 2003) consider BOD_5 content limits of 10, 20 and 30 respectively (using stricter criteria for human crops than for fodder). Jeong et al. (2016) revised DOB_5 limits from many countries: also from < 10 mgL^{-1} to < 30 (in US-EPA) and to < 25 mgL^{-1} (in Greece), and for unrestricted irrigation is considered < 8, < 10 and < 20 mgL^{-1} in South Korea, Israel and Italy, respectively. Therefore, regarding DOB_5, the pilot project can filtrate properly the effluent to be used in a drip irrigation system.

The results of SStot for each of the system drums and at the beginning of the experiment (a: when Drums were clean), for two samples (b and c) of the first phase (flow of 108.5 mLmin^{-1}) and of another sample (d) from the second phase (higher flow: 1140 mLmin^{-1}) are present in Fig. 2. As can be observed, the removing capacity after three drums is always higher than 98%. Experiments conducted by other authors, such as Adin and Elimelech (1989), concluded that the removal ratio for all particles measured increases with grain size and bed depth.

In this sense, and considering that lapilli size used in this pilot project goes form 0.020 and 0.002 and it is filled at a height of 0.7 m, high removal rate is obtained. Higher rates of SStot removal were obtained at the beginning. Once the system was functioning, lower but enough suspended solids elimination was obtained. Adin and Elimelech (1989) also mentioned that the removal ratio for all particles measured decreases with filtration velocity, affecting more the lower particle size range. In this experiment, the results demonstrate that even using the faster flux, the designed system obtains an effluent quality that can be use in drip irrigation system. The first drum clearly showed higher removal capacity. Higher initial contamination values, but also differences in the water flux among D1 vs 2 and 3, are probably influencing these results. Although differences in inflow effluent quality resulted in variable SStot quantities at the outflow, SStot values obtained (frequently lower than 10 and always < 35 mgL^{-1}) were under those considered as risk values (50 mgL^{-1}) (Nakayama et al., 2007). These authors also pointed out that a suitable combination of type, size, and capacity filter unit is required in drip irrigation system to proper maintenance.

According to Spanish Water Reuse Law (R.D. 1620/2007) which establishes the legal regime for the reuse of treated water, the maximum of SS allowed to reuse reclaimed water must be 35 mgL^{-1} for drip irrigation (< 20 mgL^{-1} for food in direct contact with water),

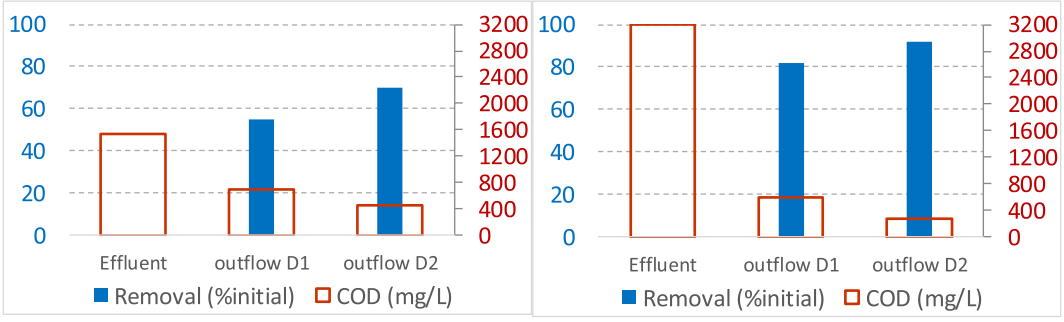

Fig. 1. COD (mgL-1, right axis) for ruminant effluent, and after filtering in D1 and D2 (outflowD1 and D2) for two samples: one from the first phase (flow of 108.5 mLmin-1, left) and another one from the second one (higher flow: 1140 mLmin-1, right). Axis on the left presents the rate of removing from the effluent on each component.

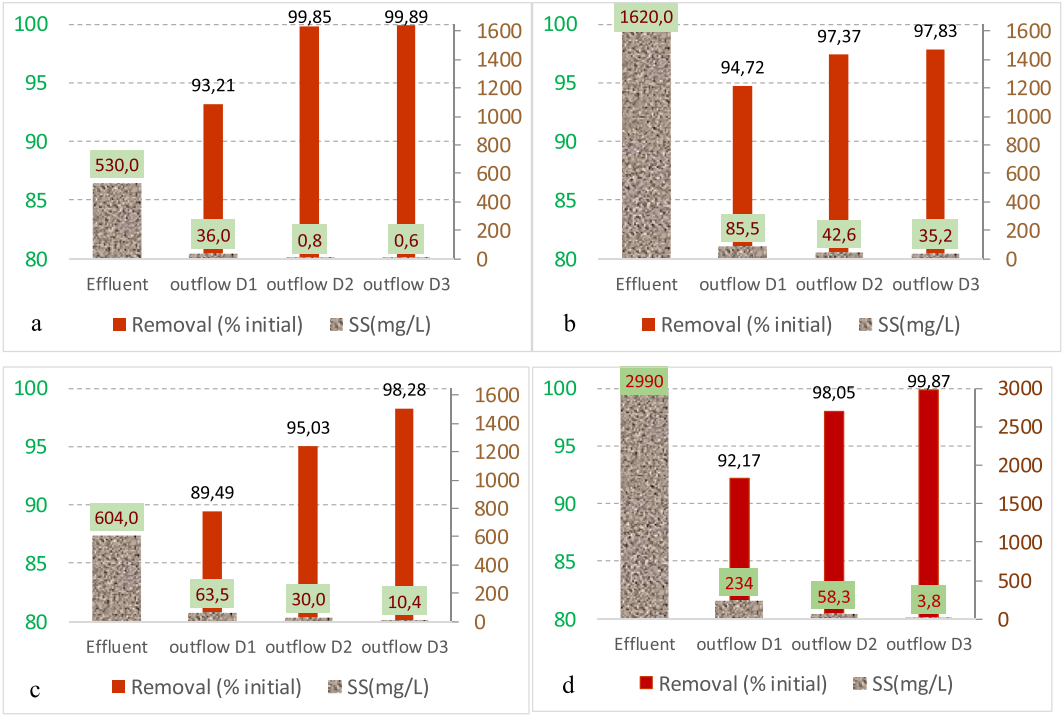

Fig. 2. SStot (mgL^{-1}, right axis) and removing rate (%, left axis) for: ruminant effluent and after passing each of the system components (D1, D2 and D3 outflow). a: at the beginning of the experiment (when Drums was clean), for two samples (b and c) of the first phase (flow of 108.5 $mLmin^{-1}$) and of another sample (d) from the second phase (higher flow: 1140 $mLmin^{-1}$).

close to the maximum obtained value. Jeong et al. (2016) revised SStot limits from many countries: also < 15 mgL^{-1} for unrestricted irrigation is considered in Cyprus and France and < 10 mgL^{-1} in Greece, Israel and Italy; while < 30 mgL^{-1} for processed food crop in US EPA, < 35 mgL^{-1} in Greece (restricted) and < 60 mgL^{-1} in Portugal (without limitations). Therefore, after the livestock effluent crossed the 3 drums, SStot were always under the maximum ones permissible in reclaimed water guidelines of many countries.

As presented in Fig. 3 (left), volatile SS represent a great proportion (88%) of total SS from the effluent. After going through the filtration system, their ratio respect SS total decrease at a rate of 77%. Therefore, the proposed filtration system has a great effect on the SSvol contents elimination, which reaches a value of 98% (Fig. 3, right). This fact is contrasted with results obtained in other EWNS (Vymazal et al., 2017), in which low pharmaceutical removal capacity was measured on filtration systems. In this sense it is worthy to note that pharmaceutical and other organic products are normally associated with DQO fractions. Besides, the presence of allophane, which gives high adsorption capacity to lapilli, is probably the responsible for this good SSvol elimination rate. In Canary Island, a study was conducted to analyse the use of "lapilli" as a material for EWTS (Sustradep, 2008). The study concluded that it has a high potential for substances removal from effluents by adsorption. Therefore, it is an optimal material to reduce organic matter and microorganisms and, where available, this material is the optima for the proposed design. In spite of this, other authors using lapilli in one of EWTS phases and which applied a horizontal subsurface flow, found a good reduction of organic matter (MO), the SS and pathogens, but also some risk of transmission of Salmonella (Abreu-Acosta and Vera, 2011).

As the time pass, the system will be partially clogged. Nivala et al., 2012 pointed out that the cumulative biological, physical and chemical treatment processes that occur in treatment wetlands can result in gradual clogging of the porous medium. As clogging may result in hydraulic malfunction and/or reduced treatment performance, an intervention is required. These authors recommended the use of finite element analysis models to simulate clogging development in subsurface-flow treatment wetlands, which will be the objective for the next step of this project. Also, they analyzed various management strategies to

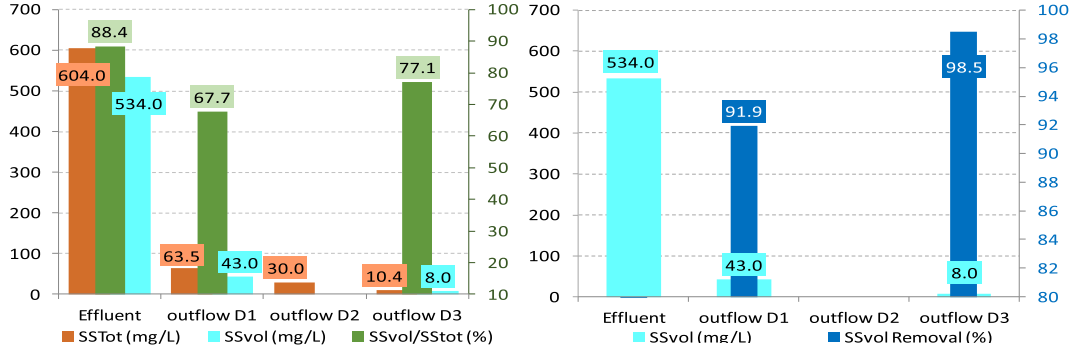

Fig. 3. Left: total and volatile suspended solids (SStot and SSvol, in mgL^{-1}, in left axis) and the SSvol/SStot ratio expressed as a percentage (right axis) through the filtration system: Effluent and drums 1, 2 and 3. Fig. 3, right: SSvol content in mgL^{-1} (left axis) and rate of elimination expressed as a percentage (right axis).

Table 1
Mean and stand deviation nutrient contents (in mgL^{-1}) for E, D1out, D2out and D3out and removing rates (R, in %).

	Nt		P		K		Ca			Mg			Na		
	mg/L	%	mg/L	%	mg/L	std	%	mg/L	std	%	mg/L	std	%	mg/L	std	%
	mean	R	mean	R	mean		R	mean		R	mean		R	mean		R
Effluent	220	0	27	0	307	15	0	154	14	0	61	4	0	370	9	0
D1out	110	50	8	70	142	51	54	212	22	−37	62	8	−2	353	33	4
D2out	48	78	< 1	96	87	24	72	149	23	3	59	16	3	356	36	4
D3out	41	81	< 1	96	57.1	7	81	94.5	5	39	22.1	13	63	340	7	8

	B			Cu			Fe			Mn			Zn		
	mg/L		%	mg/L		%	mg/L		%	mg/L		%	mg/L		%
	mean	std	R	mean	std	R	mean	std	R	mean	std	R	mean	std	R
Effluent	1.29	0.1	0	2.59	0.3	0	6.73	1	0	0.19	0.1	0	0.18	0.1	0
D1out	1.15	0.04	11	1.01	0.3	61	0.78	0.2	88	0.14	0.03	24	0.18	0.1	3
D2out	1.10	0.04	15	0.69	0.2	74	0.61	0	91	0.08	0.05	59	0.14	0.03	25
D3out	1.01	0.01	22	0.43	0.01	84	0.50	0	93	0.08	0.02	59	0.13	0.02	31

extend the life of clogged treatment wetlands, including gravel excavation and/or washing, chemical treatment, and application of earthworms. In this sense, washing of lapilli is an easy strategy to be used in this pilot project. Besides, once the filtration system becomes clogged, the lapilli could be easily regenerated by spreading it in thin layers exposed to solar radiation. Furthermore, once clogged, lapilli potential use as soil amendment has been already mentioned (Ballantine and Tanner, 2010).

Mean and stand deviation nutrient contents (in mgL^{-1}) for E, D1out, D2out and D3out and removing rates (R, in %) are presented in Table 1. High removal rates were obtained for macro nutrients NT, P and K and micronutrients Cu, Fe, Mn; moderate for Ca and Mg, and Zn and low for B and Na. Ca and Mg presented anomalous behaviour as its contents after passing D1 are frequently higher that found in the effluent. The low boron removal may be explained by the tendency of this element to form organic complexes (Yermiyahu et al., 1988), which prevent the adsorption by the same mechanism of phosphorus adsorption.

Mean N contents (in mgL^{-1}) rates from total N and removal rates (in %) by the different forms of N are presented in Table 2. Low proportion of organic N is detected in the effluent (10%) and most of it is removed (only 0.5% in D3out). High removing rates were obtained for ammonia (most of which is transformed to nitrate), reflecting the high nitrification capacity of this aerobic system, avoiding N gas emissions. When establishing higher flows this result must be revised.

To take into account sustainability and environmental considerations, a numerical example of N balance under different N inputs for C4 grass species with medium yields (comparable to C3 plants) is given in Table 3. Considering different rates of evapotranspiration (column 2: low to very high values), total N addition to soil-plant media is calculated (third column). High quantities of N are added if effluent is without mixing with water. N addition vs absorption is calculated (column 8), in which values higher than 100 implies N excess. As observed, if a high yielding crop is cultivated, no excess of N will be, because N addition (column 5) is lower than N absorption (column 8, in proportion). If lower yields are expected (9), during the rest of the year the effluent must be mixed with water to avoid N excess.

Table 2
Mean N contents (mgL^{-1}), rates from total N and removal rates (in %) by the different forms of N ($N_i = N_{iNO3} + N_{iNO2} + N_{iNH4\ and}$ $N_T = No + N_i$).

	Effluent mg/L	% tot N	D3 out mg/L	% tot N	Remv. Rate %
N_T	192.0				
NH_4^+(as N)	173.4	90.3	1.9	12.5	98.9
N_{No2}^-			3.9	9.9	
N_{No3}^-			40.9	77.1	
N_i		90.3		99.5	
N_0	18.6	9.7	0.2	0.5	99.2

As can be seen in Table 3, it is necessary to mix effluent and water in a proportion of under 40% in summer and 60% in winter to avoid applying N over the total crop requirements. If high yield is expected, only in summer (when irrigation dosage increased) it would be necessary to mix: for instance, a proportion of under 40% in hot summer days (when irrigation dosage increases to 9 l/m2 day) and 60% in spring and fall (when irrigation dosage increases to 7 l/m2 day). In these conditions, only winter effluent dosages will let to a sustainable management, although it is easy to mix effluent and water. P and K are not limiting factors because their contributions never exceed 30% of plant requirements.

Considering legal aspects, obtained effluent quality is similar of that a reclaimed water. However, proper management at field is necessary to avoid sanitary risks. In this sense, the use of subsurface drip irrigation systems is the perfect combination with treated livestock effluent reuse. This conclusion coincides with what was pointed out by (Trooien and Hils, 2007) who mentioned that subsurface drip irrigation was a new technology for livestock wastewater application, and even though effluents contain many types of materials that can readily clog emitters, the advantages strongly favor the use of such effluents for agricultural irrigation.

Spanish manure management guidelines obligate to apply the effluent produced by 3.5 cattle in one ha. With the proposed system, depending on the ET values, more than 150 cows can safely use 1 ha to dispose their liquid manure. On the other hand, at a 108 $mLmin^{-1}$, the system is only able to treat 0.156 m^3 per day, which means that using the tested flow, the system it is only feasible to treat the effluent produced by 2.6 cows. In a second phase, higher flow of 1140 mL min^{-1} (equivalent to 1.64 m^3day^{-1}, 28 cows) was studied to be used by conventional small farms, which are 94% of total cow farms in Canary Islands. As presented here, similar results of quality parameters were obtained when using this higher flow. However, it was observed that the inflow system must be improved to use all the lapilli located into the drums, avoiding preferential flow. As a conclusion, only if managing all the factors implied in the proposed effluent system treatment, sustainable results will be obtained.

4. Conclusions

The design presented in this paper is an “on site” pilot scale cattle

Table 3
Evapotranspiration (from low to very high values), total N addition to soil-plant media, water applied (L year^{-1}), N addition, high expected yield, N absorption (kg/ha), N addition vs absorption (%, values higher than 100 implies N excess), regular expected yield, N absorption and N addition vs absorption.

mg N/L effluent	L/m2 day	mg N/m2 day	L/year	N kg/ha[a]year	Yield kgDM/ha	N absorp kg/ha	N (%)[a]	Yield/ha kgMS/ha	N absorp kg/ha	N (%)[a]
41	3	123	1095	448.95	100000	1440	31.2	25000	360	31.2
41	7	287	2555	1047.55	100000	1440	72.7	25000	360	72.75
41	9	369	3285	1346.85	100000	1440	93.5	25000	360	93.55

(1) N contents in treated effluent (mg/L).
(2) Typical Evapotranspiration rates of Winter, Spring and Autumn and of hot Summer days (L/m2).
(3) Added N by irrigation by each ET (mg N/m2 &day).
(4) Total water amount by year (L/m2 & year).
(5) Added N per year by irrigation by each ET (kg N/ha & year).
(6) Expected yields (high) expressed in Dry matter (kg DM/ha & year).
(7) Total amounts of absorbed N by plant (kg N/ha & year) considering high yields.
(8) Added N/absorbed N (%): (5)/(7).
(9) Expected yields (medium) expressed in Dry matter (kg DM/ha & year).
(10) Total amounts of absorbed N by plant (kg N/ha & year) considering medium yields added N/absorbed N (%): 5/10.
[a] N added/N adsorbed.

effluent treatment focused on low-tech and low cost solution in terms of finance and energy, which does not require the addition of chemicals. The effluent's quality obtained with the lapilli's filtration allows it to be injected in a drip system with low risks of obstruction. The pilot system allowed obtaining elimination values for the main parameters of effluent's quality (TSS and COD) similar or greater than the ones obtained in other treatments of low cost and energy. The VF, SDI and fodder crop combination provide an optimal solution to small farms, controlling sanitary risks. The tested flow allows using this system by conventional small farms, which represented 94% of total cow farms. The inflow system must be improved to use all the lapilli located into the drums, avoiding preferential flow. Characterization of the hydraulic and chemical behaviour of the system must be conducted in long-term to evaluate its maintenance requirements and potential clogging hazards. All the factors implied in the proposed effluent system treatment must be simultaneously managed to obtain sustainable results. Circular economy contributes to “closing the loop” of product life cycles through greater recycling and re-use. In this sense, the presented system is a sustainable solution to avoid environmental risk and achieving on farm zero discharge. Following studies must determine if emergent substances, not only by the filtration system, but also by the irrigated soil, are properly degraded.

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Appendix A. Supplementary data

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